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Voluntary Isolation of Control in a Natural Muscle Group

By

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PREFACE

I take this opportunity to express my keen sense of obligation to my many friends whose help has made it possible for me to write this paper. Especially to my teachers, Professor James Rowland Angell, Professor John B. Watson, now of Johns Hopkins University, Professor George B. Mead, and Professor Edward S. Ames, I owe much for their stimulating instruction and timely encouragement. Professor Harvey Carr gave me valuable suggestions as to the construction of apparatus.

I am also much indebted to my laboratory assistants, Mr. George H. Payne, Mr. Mark H. May, and Mr. George W. Middleton, who served in double capacity, as subjects, and, in the tests on the writer, as experimenters. To the students and teachers who gave so much of their time in serving as reagents in my experiments, I am particularly grateful.

My wife has given me great assistance in the reading, translating, and interpreting both German and French literature, treating of the problems discussed in the following pages.

J. C. B.

Maryville College, August 15, 1912.

INTRODUCTION

Statement of Problem

The investigation recorded in this paper was begun in the fall of 1909 and was continued through the academic years of 1909-1911 and the summer of 1910. Publication of the results has been unfortunately delayed. It was hoped that by a long series of tests involving a careful examination of the voluntary control processes of the movement of the ring finger in both vertical and horizontal planes, and by a careful investigation of the inhibitory processes of the other fingers, some additional light might be cast both upon the problem of voluntary control of movement and upon the nature of the process of inhibition. The problem involved the determination of the mental antecedents of the movement, the mental concomitants which controlled it and the nature of the psychical processes involved in inhibition. The working out of these problems raised questions as to the nature of automatic action and imageless thought.

Previous experimenters have studied the growth of control in muscles over which normally we have little or no mastery, like the muscles of the external ear; or the methods of gaining new dexterities like type-writing with muscles over which we have a high degree of control. The present experiments differentiate themselves from both the preceding cases in dealing with the isolation of control over special muscles in a group which ordinarily contract together. Movement of the ring finger tends strongly to carry with it movement of the adjacent fingers. Our procedure, as will be seen, involves the suppression of the movement of these neighboring fingers and the development of the coordinations of the ring finger alone.

As the solution of our problem depended largely upon the introspective reports of the subjects who acted as reagents in the experiments, it was thought best to select persons who had had work in psychology. The persons serving as subjects were

either instructors, graduate students in psychology, or senior college students that had taken one or more courses in the department. Twenty-two men and ten women were used and it may be said at once that no characteristic sex differences appear in the results.

In general outline the experiments fell into four series. In the first series, movement went on without any instruction as to method and without any limitation of the governing senses. Tests of the voluntary control of the fourth, or ring finger, of right and left hands were made for both vertical and lateral movements.

In the second series of experiments, movement was accompanied by a limiting or distracting process. This distracting process consisted in (1) the use of the blindfold; (2) counting aloud blindfolded; (3) reading aloud; (4) reciting a piece of poetry while blindfolded; and (5) attending to the tick of a metronome. The movement in each case was undirected as to method of control, but directed as to amplitude, and as to rate, when the metronome was used.

In the third series of experiments, tests of the pressure of the middle and little fingers were made. In this series the vertical movements only were used. One half of the subjects were instructed to relax and the others to hold the fingers rigid, while the fourth finger moved.

In Series I, II, and III, the hand was supported on a table, so it was thought best to test the control of the fingers without any support for the hand save the carpal joint. Therefore, in the fourth series, the forearm was placed in an arm-rest so that it was supported just above the carpal joint, thus leaving the hand free. The subjects were then instructed to relax the fingers.

Description of Apparatus

The tridimensional apparatus for registering finger movement was not suitable for the purpose of our investigation, so we devised one apparatus for registering finger movements in the vertical plane and another for registering movements in the

horizontal plane. Two drums, 30 centimeters in length, were placed three meters apart on a long table and joined by a smoked paper belt; this enabled us to use more than six meters of kymograph paper without change, and provided space enough to register the movements of the fingers of six reagents. The progress of each subject was easily followed from day to day, and the records of the movements relative to one another could be seen at a glance. The two drums were rotated by means of a small electric motor and their rate was controlled by the use of a rheostat and a Pillsbury speed reducer, to which a belt running around each drum was attached. The registering apparatus was as follows: (Fig. I) a small wooden box (X), 25 cm. x 12 cm. x 12 cm., was

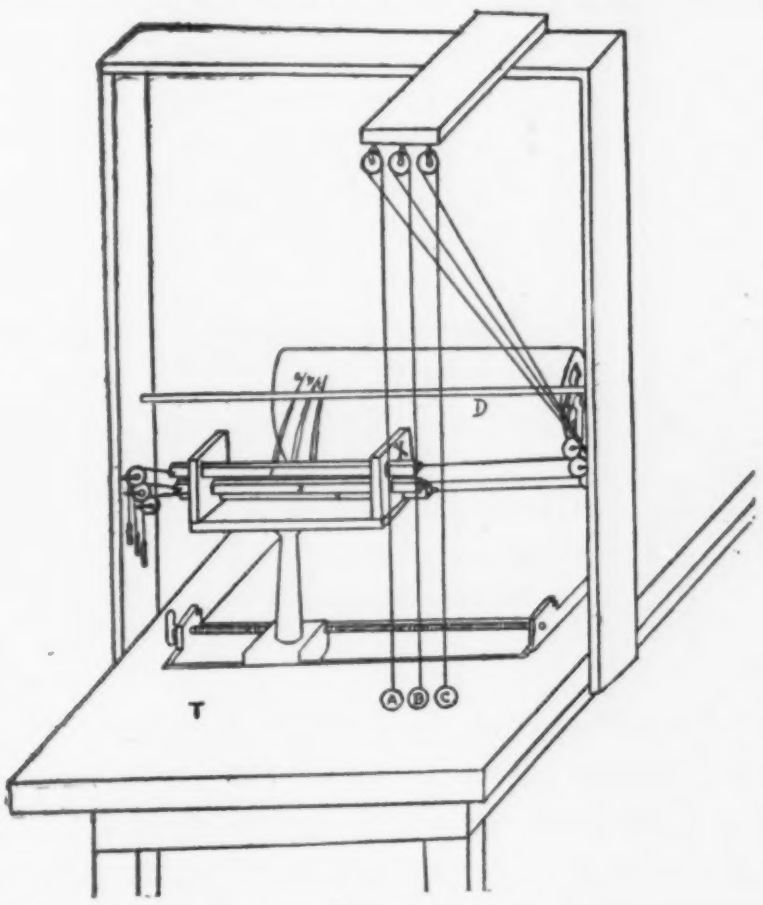

FIGURE I

placed on the carriage of the kymograph. In each end of this box were three rectangular holes, 15 mm. x 6 mm., through which ran three bars (1, 2, 3), 40 cm. x 15 mm. x 6 mm., so adjusted that they could be easily moved back and forth in the horizontal plane; to these bars cords were attached and so di-

rected by the use of pulleys that when the fingers were placed in thimbles (A, B, C) fastened to the other ends of the cords, any movement of the finger in the vertical plane pulled the bar in the horizontal plane. Weights attached by means of cords to the other ends of the bars pulled them back in place. Small holes, 3 mm. in diameter, were bored in the bars and in these were placed small pegs (a, b, c), tipped with fine wire, ground to a point, touching the smoked paper on the drum. These pegs registered the finger movements. Seconds were recorded by an electric time marker connected with a pendulum.

For recording movements in the horizontal plane, the following attachment was used in place of the box and bars described above: (Fig. II) a small box (X), 10 cm. x 10 cm. x 20 cm.,

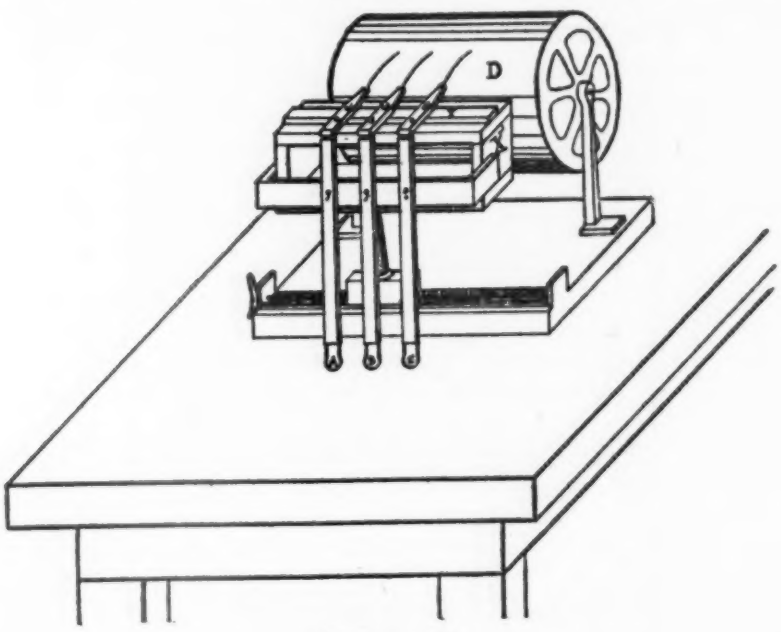

FIGURE II

attached to the carriage of the kymograph, served as a support upon which to fasten a wooden block (Y), 2 cm. x 8 cm. x 10 cm., on which markers were fastened by means of screws (1, 2, 3) which served as pivots on which the markers moved. The pivots were at a distance of 20 cm. from the small end of the rods and 10 cm. from the ends to which the upright rods were attached at right angles. The horizontal rods (a, b, c), which served as markers, were made of wood, 2 cm. x 2 cm. x 30 cm., and tapered toward the ends in which were placed small wires, 8 cm. long, curved slightly toward the ends, which were ground

to a point, so that they would mark readily on the drum. The upright rods worked on wooden pegs (4, 5, 6) as pivots running through the rods at a distance of 10 cm. from their upper ends and fastening them to the end of the box. These upright rods were made of wood, 2 cm. x 2 cm. x 40 cm., and to their lower ends thimbles (A, B, C) were attached and so adjusted as to fit the little, ring, and middle fingers when the hand lay flat on the table. The thimbles were 2 mm. above the surface of the table, so that the fingers did not touch the table during the lateral movement. This arrangement permitted the fingers and the markers to move in the same direction.

The apparatus used to record the pressure curve in Group I is shown in Figures IIIA, IIIB, and IV. T (Fig. IIIB) is a box,

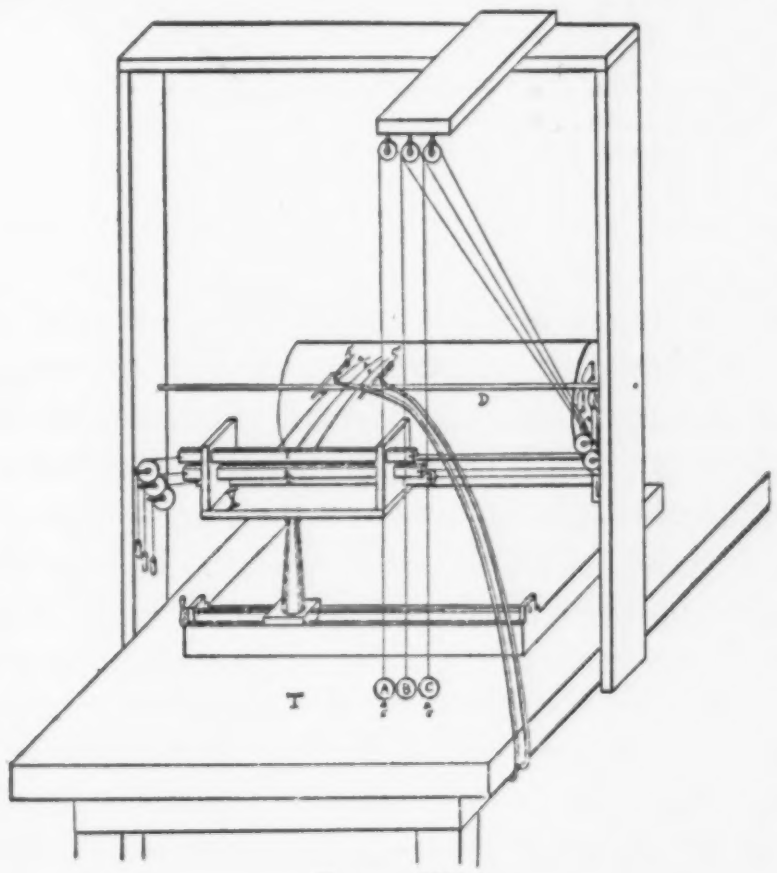

FIGURE III A

15 cm. x 30 cm. x 50 cm.; A and C are round pegs, 1 cm. in diameter, fastened in pistons of plaster of paris (B in Fig. IV), 5 cm. long and 2.5 cm. in diameter. The pistons worked in glass tubes, 10 cm. in length, and rested on coiled steel springs, 5 cm. long and 1.5 cm. in diameter. The glass tubes were fitted into

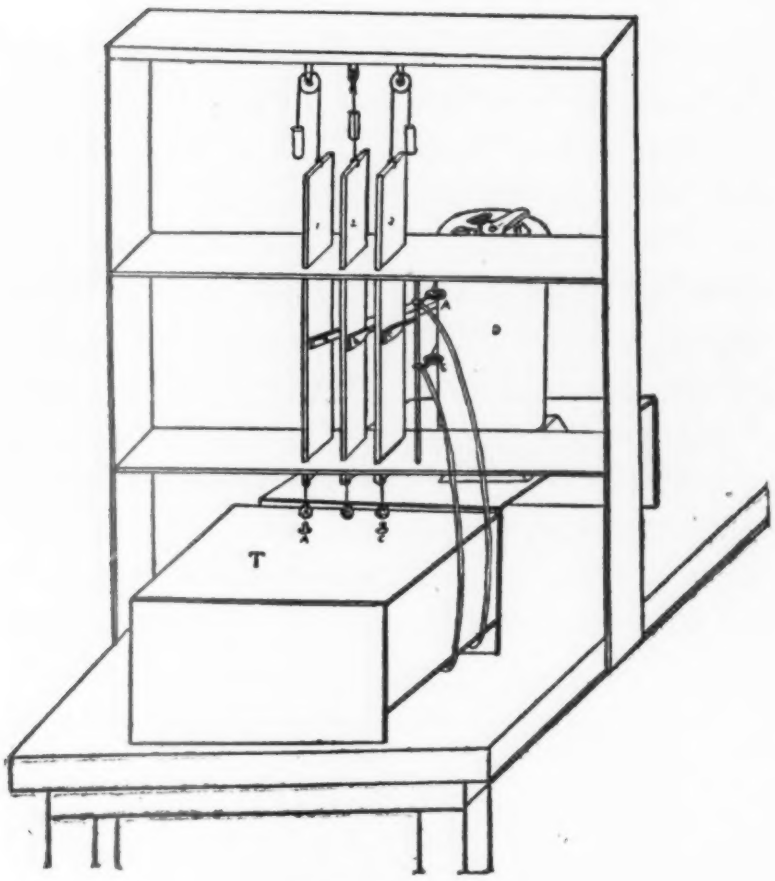

FIGURE III B

holes bored half way through the bottom of the box, and made air-tight by the use of sealing wax; through the center of the base of each large glass tube a small glass tube C (Fig. IV) 1 cm. in diameter, was inserted; the small tube extended up into the large tube through the center of the steel spring 3 cm., and distance of 3 cm. below the bottom of the box to receive the rubber tube running to the tambours A and C (Fig. IIIB). The small tubes were made air-tight by means of sealing-wax. The pegs A and C (Fig. IIIB) extended 2 mm. above the top of the box. The pistons were made air-tight by the use of oil. In this series, Group I, a vertical drum (D) and a recording apparatus (a, b, c), attached to vertical bars controlled by weights were used, as shown in Fig. IIIB. In Groups II and III a horizontal drum was used.

STATEMENT OF METHOD

The subject sat on a laboratory stool at the end of a table, placed his little, ring, and middle fingers in the thimbles with

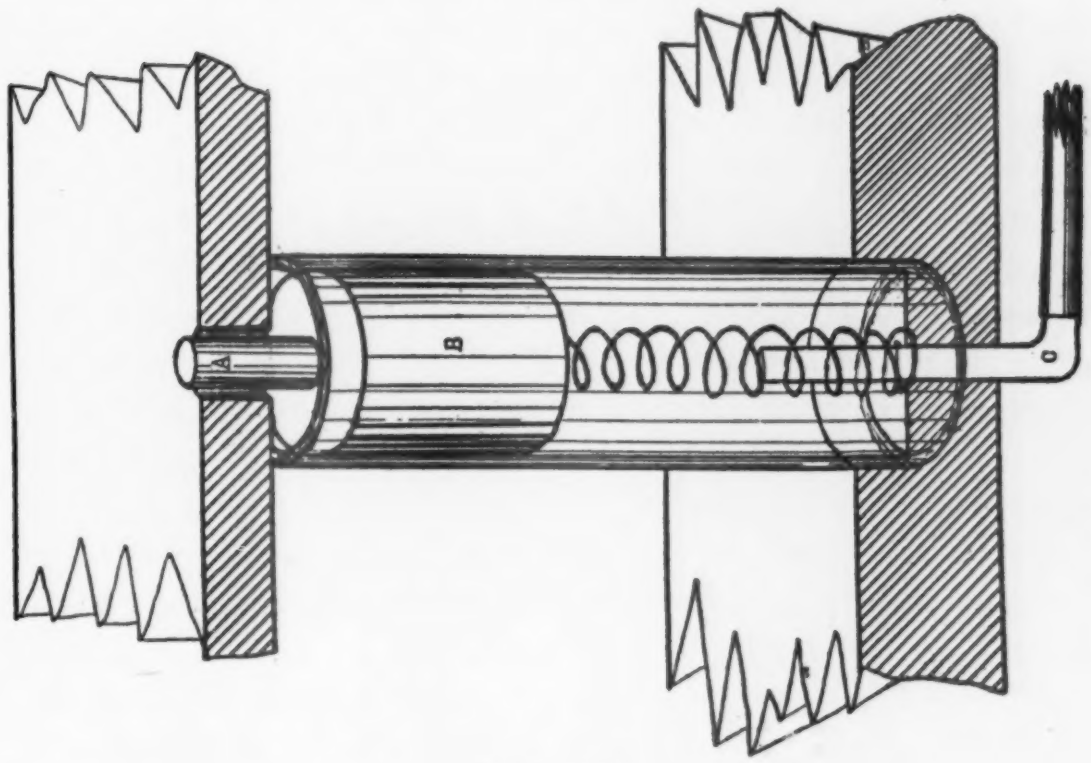

FIGURE IV

the palm of his hand laid flat on the table, and let his arm rest comfortably thereon. No directions were given in regard to the position of the other members of the body. The signal to move was given by means of a small electric bell. A few seconds before the signal to move, the signal "ready" was given.

The ring finger was selected first, because of the comparative ease with which apparatus could be adjusted to it, and because of its convenience for experimentation. In the second place, it usually has the least independent action of any of the fingers, hence would yield the best results for this experiment.

The subjects were tested daily for eighty seconds, and the tests were continued until the control process was practically perfect in each series. Conditions were kept as nearly constant as possible throughout the experiment. The test was given at the same hour each day. Any variation in the health or condition of the subject was noted.

We began the first series by requiring the reagent to move for one hundred seconds at each test; this was too long to secure the best results, as the fingers became so fatigued that control became impossible, so we reduced the time to eighty seconds. In

the first series, we let each subject choose his own rate at first. We next tried various rates of 60, 70, 80, 90, and 100 movements per minute. The results are recorded below.

The objective side of the experiment consisted of a curve recorded, as already indicated, on the belt of smoked paper, passing over the two drums, by markers attached indirectly by means of cords, pulleys, and thimbles to the fingers. The time of the test and the position of the fingers during the same are accurately recorded. This method permits a careful study of the movement and control of each subject and his progress from imperfect to perfect control. The kymographic curves recorded by the six observers on the paper ran parallel to each other and each record was continued from day to day so that it was quite easy to follow the progress of the subjects.

Immediately after each test, the subjects were asked to describe what took place in their minds from the giving of the signal to start until the close of the test. As the experiment progressed, our questions were made more searching, and so the introspective reports are more definite. The nature of the initial cue, the control factor in the moving finger and the other fingers, the focal point of attention, were searched for, and usually they were clearly and definitely given by the subjects in their introspective reports. A study of these introspections enabled the writer to determine their respective mental types. The immediate mental antecedents operative in initiating the movement, we term the "cue". The mental concomitants of the movement, which seemed to guide the same, are termed "control processes".

PART I

Series I.—Uninstructed Movements. No Distractions or Limitations—Seven Subjects

1. Vertical Movements

a. *Preliminary statement*

It is not our purpose to make an historical study of the various theories, of volition, but rather an introspective study of voluntary motor control under experimental conditions, checked by objective data. We have laid special emphasis upon a study of the initiatory cue of the movements made and the control process of the movement after it has been initiated. These processes vary according to the mental imagery of the different subjects, and also according to the degree of control acquired by each. Several of the subjects reported that the could vary the initiatory cue at will, by concentrating the attention upon the visual image of the movement to be made or upon the kinaesthetic image, or even upon the signal. But as a rule the mental type of each reagent determined his initiatory cue and his control process also.

The records of this series were made with the eyes of the subjects open and without any restrictions whatever. The reagent, having taken the position described in the previous section, was directed at a given signal to move his ring finger, with the meta-carpo-phalangeal joint as a pivot, as high as he could without moving the other fingers. He was told to control his other fingers—that is, he was to keep the ring finger moving and the other fingers on the table. The records of the finger movements of the subjects were small at first and revealed many movements of the middle and little fingers. Practice rapidly lessened the number of these accessory movements in each test and increased the extent of movement of the ring finger. The series was continued until the latter movement was practically automatic, or until the control was substantially perfect. Even after the control had become perfect, fatigue, headache, nervousness, or

worry on the part of the subject were followed by irregular reactions.

The curves at the beginning of the first series show an irregular record, both in extent and in rate. The height of the curves is small and irregular in all of these early records except two; two subjects moved rapidly from the first, but their control of the other fingers was slight. They desired to make a large movement and so did not emphasize control, and the result shows that the little finger and the middle finger move in rhythm with the ring finger. The other four reagents made smaller movements with the ring finger, but show better control of the other fingers.

Three of the subjects had a tendency to raise the hand from the table at the metacarpo-phalangeal joint; this placed the hand in a strained position, but enabled the reagent to make a more extended movement of the ring finger and gave him better control of the other fingers as he was enabled in this way to place them under more muscular tension. Two of the subjects broke up this habit after several weeks' practice, but the other kept it for nearly four months.

Five of the subjects took a slightly leaning posture toward the hand that was active in the experiment. The whole organism was adjusted to this one activity. Sometimes the other hand would move as if it too were engaged in the work. Adjustment and tension of the muscles were observed quite frequently in the non-acting hand. This fact emphasizes once more the law of excess discharge, the tendency of the motor impulse to be drained off into channels other than those immediately essential and especially those of an anatomically symmetrical kind. During the first set of tests one reagent kept time by nodding her head as she moved her finger and counted one, two, etc., with each stroke of the finger. She gained perfect control after a few days' practice. The movement of the ring finger was not so extensive as that of the records of the other reagents, but her control of the other fingers was perfect after a few tests. Her speedy control was presumably due to the fact that she had had daily piano practice from childhood.

The first and second phalangeal joints of the fingers of three of the subjects were loose, and so the curves representing their records do not show the actual movements that took place, while using the metacarpo-phalangeal joint as a pivot. This difficulty was overcome after considerable practice. Finally the subjects were able completely to relax the muscles and tendons controlling the movements of the fingers, and then the control of the fingers to be kept quiet was perfect, and the movement became practically automatic.

Bair[1] says that learning to make a voluntary movement is largely a matter of learning to relax. Relaxation is first learned by withdrawing the attention from the movement just effected. A voluntary attempt to relax will merely increase tension. Our experiments show that the inhibition of the movement of a member of a group is first learned by keeping the member rigid by muscular tension and secondly by drawing the attention from it. The latter is the method by which complete relaxation is acquired. The kind of material in the focus of attention, which serves as initial cue and as control in the moving process is determined by the mental type of the reagent. We shall consider this more fully below, where we describe and analyze the introspections of the subjects that acted as reagents in our experiment.

In the following introspective accounts, tests of different chronological position in the series are presented in order that they may show a greater variety of conscious phenomena at the different stages of the problem. The experimenter rigorously avoided suggesting the special things reported. The terms used in the introspective accounts have their ordinary meaning. Kinaesthetic sensations are feelings of tension, movement, and the like, resident in the moving member and due to the latter's movement. Kinaesthetic images[2] are memory images in which kinaesthetic sensations prevail. Auditory image and visual image are used in a similar manner. Visual-kinaesthetic, auditory-kinaesthetic and auditory-visual, indicate the fact that both elements were present, the more vivid element being placed first.

[1] Psychological Review Vol. VIII, 1901, p. 470.

[2] Whether these are pseudo-images, in reality sensations, need not be discussed. They were reported by the reagents as images and may so stand here.

b. Right Hand

(1) *Introspective Reports*

Subject P.

First Trial.—The initial cue was a visual-kinaesthetic image and visual and kinaesthetic perceptions were the control processes. Attention on extent of movement of ring finger. Attention oscillated. Saw little finger raised, attention was attracted to it, and then followed an irregular movement of ring finger. The latter became fatigued toward the close of the experiment, and the extent of movement became less, and the rate irregular. Motor control was lost after fatigue became great. Thought of record that he was making on the drum.

Fiftieth trial.—The initial cue was a visual image of the anticipated movement. Watched the members of the group. Attention was centered on control of all the fingers rather than on extent of movement. Paid, however, little attention to anything. Movement was practically automatic. Heard a locomotive whistle.

Subject B.

Fourth trial.—Visual image of movement was the initial cue. Visual-kinaesthetic perception was the control process. Tried to concentrate attention on the ring finger and its movement. Little finger was drawn up by the weight which pulled the recorder back into position. Attention oscillated to the little finger. Middle finger moved next and drew attention to it. Was conscious of making a poor record which seemed to distract attention and cause embarrassment. Conscious of fatigue in little finger.

Sixtieth trial.—Had a vivid visual image of the movement before the finger began to move. Attention on regular movement of ring finger and control of the other fingers. Visual perception of the moving finger controlled its movement both as to extent and regularity. Conscious of good control.

Subject S.

Second trial.—Visual idea of the movement was the initial cue. Movement was controlled by visual perception of the ring finger. Attention on extent of movement of ring finger. Raised little finger once. This attracted attention to it in order to put it in position. No fatigue, but conscious of strain in arm.

Sixtieth trial.—Visual-kinaesthetic ideational cue. Attention on extent and regularity of movement which was guided by muscular feeling in the ring figner. Some muscular strain in hand. Little finger moved slightly; watched it to keep it down.

Subject G.

Eighth trial.—Kinaesthetic image of the movement was the initial cue. Attention on movement and on trying to keep the other fingers still. They both moved and attention was attracted to them. When attention was focused on putting little finger down on the table, the ring finger did not make its usual record. Was conscious of this at the time but unable to prevent it. Felt pain in the region of the scapula. Conscious of effort in the ring finger.

Fiftieth trial.—Kinaesthetic image was the initial cue. Arm ached at the beginning in making the adjustment. Attention was centered on keeping other fingers down and on trying to make a good record. Felt that she was making a good record and wondered why. Tried to relax arm. Kinaesthetic perception of the moving finger.

Subject M.

First trial.—Kinaesthetic image of ring finger preceded the movement which was controlled by resident sensations. Tried to move ring finger. No thought of other fingers. Felt that ring finger would not move rightly.

Fiftieth trial.—Visual-kinaesthetic imaginal cue. Visual-kinaesthetic perception of ring finger controlled the movement. Attention on moving more slowly than usual and also on extent. Just let the finger "go itself". Had no difficulty in keeping the other fingers from moving. Did not keep attention on the finger all the time toward the close of the test. Movement was practically automatic.

Subject K.

First trial.—Visual image preceded the movement which was controlled by visual perception of ring finger. Attention was focused on the movement of ring finger, but it oscillated to middle finger and to little finger. Felt fatigue in forearm.

Thirtieth trial.—Visual image initiated the movement. Attention on extent of movement and on the perfect control of the other fingers. Had a visual image of the record as it would appear on the drum. Conscious of perfect control.

(2) *Summary of Individual Introspections*

The introspections reported by the reagents show that attention was generally focused upon the idea of the extent of movement of the ring finger. The subjects as a rule emphasized extent of movement too much, and consequently they were unable

completely to inhibit the movements of the middle and little fingers.

M. reported that he could control his movement better when he moved the finger rapidly—at the rate of sixty or seventy times per minute. He reported also that this gave him better control of the other fingers. This report is confirmed by a study of the curve recorded on the kymograph.

P., on the other hand, moved deliberately and soon gained complete control of his fingers. In the first four or five tests, he reported that he had difficulty in getting definite resident sensations in the moving finger, and the record shows a corresponding irregularity in the movements of the ring finger and inability to inhibit the movements of the other fingers. After a few tests he focused his attention with regularity on extent of movement, and was able to disregard the other fingers. He said that he had no thought of them. When *attention* was focused *completely* upon the movement of the ring finger, its record was even and regular and the *inhibition* of the other fingers was *complete*.

G. was ambitious from the start to make a large movement. Her attention was focused on extent of movement rather than on voluntary control. It took many trials to eliminate the movements of her other fingers. This was due in part to the size of the thimble which was too large for her ring finger and so slipped at times, thus causing the other fingers to move.

During the first set of this series G. reported that while her attention was focused on extent of movement, the latter was controlled by a visual perception of it. Whenever her other fingers were drawn up by force of the weights or moved in the effort to move the ring finger, if attention was attracted to the little finger or the middle finger, it was *after* the movement had taken place. Sometimes, one of the other fingers would be pulled up gradually by the weights without any knowledge on the part of the subject of the position of the finger; but in the effort to move the ring finger or in the effort to make sure that the other finger was down, the latter moved and then attention was directed to it. Quite frequently the record shows that the other fingers moved without the knowledge of the subject.

G. reported muscular fatigue and strain in the muscles of the forearm just below the elbow and in the muscles of the arm in the region of the scapula, whenever the test was continued longer than eighty seconds. She reported also sensations of strain in tendons of fingers and hand. When her attention was strongly focused on the movement of the finger of the right hand, she reported a twitching of the muscles in the left forearm. Extent of movement was judged by the tendinous strain in the moving finger.

S. was able to make a large movement from the first; this was largely due, as we have said above, to the shape of his hand and fingers. When the palm of his hand was placed flat on the table, the tips of his fingers, when in their normal position, were not touching the table. This fact made it more difficult for him to control his other fingers, when he was moving his ring finger, because his joints are loose and permit the fingers to bend back readily at the phalangeal joints. It took him a long time to overcome this.

His control process was a visual image of the curve that he was making on the drum by the movement of the ring finger. A visual image of the record guided his movements both as to extent and regularity. Only once during Series I, which was continued for two months and a half, did this subject report kinaesthetic perception—the feeling of the moving finger—as the process which guided his movement. His movement finally became semi-automatic and his control perfect for several days at a time and then a day would come in which he could not inhibit the movements of the other fingers. This could usually be accounted for by overwork—mental or physical. He always reported attention attracted to the other fingers *after* their movement. He frequently reported strain in the tendons of the back of the hand and in the moving fingers. Toward the close of this series his movement was so nearly automatic that he gave little attention to the fingers, and so reported only very vague visual images of his movement.

K. was very definite and accurate in his introspective reports. His control was poor at first, but his determination to succeed,

and his ability to concentrate his attention on his problem hastened the learning process, so that he gained perfect control of his fingers in the course of two or three weeks. In the early part of Series I, he reported a conscious struggle with his thumb which had a strong tendency to move, but it was controlled with great effort. He was the only one that reported any tendency to move either the thumb or the forefinger.

His starting cue was strongly visual from the first. His control process was also strongly visual, and usually consisted of the visual image of the movement of the finger. Quite frequently he reported that his movement was controlled and regulated by a visual image of his record on the drum. These facts are more clearly and definitely brought out in the blindfold series. K. *learned* to control his fingers more quickly than the other subjects, owing to his concentration and his determination to succeed. At first he was not able to control extent of movement of the ring finger, and was not able to inhibit the movement of the other fingers. Although he learned more rapidly than the other subjects, he did not gain perfect control so quickly as Sn. because she had good control from the very first in Series I and II.

B (the writer) was much older than the other subjects, and was not able to make so extended movements as they, nor was his record so uniform from day to day. In Series I, his starting cue was uniformly visual, and his control was the visual perception of the moving finger aided by the kinaesthetic perception of the movement. From the first he was not able to inhibit the movement of the other fingers. Attention oscillated between the ring finger, and the middle finger or the little finger. But attention was always attracted to these fingers *after* their movement. This rule was uniform with all the subjects. Fatigue, worry, or headache regularly lessened the ability of the subject to control his fingers. Confidence that he could perform the experiment with perfect control was a great help toward success.

The subjects uniformly report that attention goes to the middle and little fingers *after* their movement. So long as these fingers are completely relaxed the subject reports that he is not conscious of them; but the instant they move, consciousness ap-

pears and attention is focused upon them in order to control them.

c. Left Hand

(1) *Preliminary Statement*

The left hand movement was a repetition of the right hand movement. It may be remarked that all the subjects were right handed. The purpose of this part of the experiment was to verify the results of the first part and to determine the effect of training the fingers of the right hand upon the process of learning a similar movement by the members of the left hand. Only five tests were given in this series. We give an introspective report of each individual below:

(2) *Introspective Reports*

Subject G.

Fourth trial.—Kinaesthetic image of the movement was the initial cue. The ring finger was controlled by kinaesthetic perception of it, and by visual image of it. Did not look at the hand at all. Sensation of touch as the finger came down on the table was an important factor of the control process. The other members of the group were controlled by tendinous, muscular, and tactile sensations. The tendinous strain was prominent. The kinaesthetic sensation was felt in the whole finger. Attention was focused on the movement of the ring finger and especially on the amplitude of the movement. No fatigue.

Subject Sn.

Fourth trial.—Auditory-kinaesthetic cue. There were three control processes: tactile sensation as the finger came down to the table, kinaesthetic perception, and visual perception of the moving member. The sensation of touch seemed to be very important as an element of the control process. Tactile sensation controlled the other members of the group as they lay on the table. Subject found that she was able to control her finger without looking at it; then a visual image of it appeared. Attention was focused on the movement of the ring finger.

Subject S.

Fourth trial.—Kinaesthetic cue. Kinaesthetic perception of the ring finger was the chief element of control, but visual perception of it seemed to aid in the control of the movement. Was conscious of great strain in the phalanges of the ring finger in the metacarpo-phalangeal joint and in the volar side of the wrist. The other members of the group were kept down by means of

muscular tension. Attention was centered on watching the movement of the ring finger and on the sensations in the finger. Other fingers were in the field of attention. Was conscious of good control.

Subject M.

Fifth trial.—Idea of the feeling of the movement to be made was the starting cue. The movement was controlled by the kinaesthetic perception of the ring finger. Did not watch it but looked out of the window. Other members of the group were controlled by tactile sensation of table. Had no other sensation from them. Attention was not focused on anything.

Subject P.

Fifth trial.—As soon as the signal bell rang, P. had an articular image [?] of the finger. Sensation was localized in the metacarpo-phalangeal joint. Then the movement followed. Kinaesthetic perception of the ring finger was the principal element of control—sensation continued in the joint. Tactile sensation of finger coming down on the table, was an element of control also. Other fingers were relaxed. They were controlled in part by visual perception. Attention oscillated—no attention to movement during a part of the test.

Subject B.

Fifth trial.—Kinaesthetic-visual-auditory cue. Both visual and kinaesthetic perception of the ring finger controlled its movements. Articular sensations in metacarpo-phalangeal joint. Other members of the group were controlled by visual perception and by sensations of tendinous strain in the first phalanges. Attention was focused on the amplitude of the movement.

(d) Summary of Left Hand Movement in Vertical Plane

During the right hand practice there was constant innervation of the fingers of the left hand so that when the left hand movement was begun, only five trials were given in this series because the control was practically perfect from the first in regularity and amplitude of the movement of the ring finger and also in the complete inhibition of the movement of the other members of the group. The long practice with the fingers of the right hand seemed to be the explanation for the above results. It required more than two months—sixty or seventy trials—for the subjects to gain complete control of the movement of the finger of the right hand in the vertical plane. When the fingers of the left

hand were placed in the thimbles, and the signal given, the ring finger moved almost as easily and with as great amplitude as though it were continuing the practice of the finger of the right hand. We consider this subject more fully in the general summary of the results of the experiment.

The presence of the kinaesthetic image as the initiatory cue was more common than in the previous right hand movement. The auditory cue was usually reported by subjects whose movements were practically automatic. Either auditory or kinaesthetic cues could be used successfully by some of the subjects, but the kinaesthetic image was the one generally used. M. frequently reported a visual cue; occasionally he reported a 'general idea of movement' as the immediate precursor of the finger's activity.

The movement was regulated and controlled chiefly by kinaesthetic perception of the moving member. The tendinous, articular, and muscular sensations were more carefully localized by the subjects than in the previous series. The tendinous sensations were usually localized in the first phalanges and in the fourth metacarpal but more commonly in the former and frequently in both during the experiment. Visual perception of the moving member and of the whole group was present as an element of control, but was not usually so important a factor as the kinaesthetic perception. Sn. reported that she could move the finger better without looking at it. This fact would seem to indicate that for her the visual element was not an important factor in the control process. Tactile sensation was also an element of control. As the finger came down upon the table, both the thimble and the ring finger touching the table gave rise to a vivid perception of the position of the finger.

2. Lateral Movements

a. *Preliminary Statement*

The lateral movement of the ring finger presented more difficulties than the vertical. The ligaments binding it to the little finger and the middle finger are so arranged that any extensive movement of the ring finger in the lateral direction would always pull one or the other of the two adjacent fingers; so that

the movement of the latter did not always mean that the muscles controlling them had contracted.

In the second place, movement of the ring finger in the lateral direction is not so common as movement in the vertical plane. But the second difficulty was not so formidable as the first; for, with the exception of the writer, this movement was learned rapidly with almost perfect control of the other fingers. The first records were very discouraging—all the fingers moved and even the thumb was held in a strained position and moved slightly. The records show how rapidly persistent, faithful, regular practice will overcome these difficulties.

The following introspective reports of the subjects are fair samples of the psychical phase of the lateral movement of the fingers of the right hand. In general they resemble the previous reports.

b. Right Hand

1. *Introspective Reports*

Subject G.

First trial.—Movement of ring finger was initiated by a kinaesthetic idea of the movement to be made. The movement was controlled chiefly by kinaesthetic perception of the moving finger, supplemented by a visual perception of the record as it was being made on the drum. First phalangeal joint ached. Muscular tension controlled the other fingers. Attention was focused primarily on the movement of the ring finger, and secondarily on idea of moving in such a way as not to disturb the other fingers—steadily and not extensively.

Tenth trial.—Kinaesthetic cue. Pulled down with the other fingers to try to fix them firmly, and then withdrew attention from them. Was conscious of good success. Kinaesthetic perception controlled the ring finger; visual perception of the record used out of curiosity only, but not for control. Looked down at other fingers once and felt that control was being lost, and went back to watching the record. No strain and no fatigue.

Subject Sn.

First trial.—Auditory cue—the signal initiated the movement. Visual perception of the fingers supplemented by kinaesthetic perception were the control processes. Attention was focused on the ring finger, but the other fingers took a part of the attention.

No fatigue. Kinaesthetic sensation in the metacarpo-phalangeal joint.

Ninth trial.—Auditory cue. Visual perception of the group was the chief process of control. Had kinaesthetic perception of the ring finger, and also of the little finger when it moved. Attention was focused on the ring finger, with the other members of the group in the field. Get on better when attention is focused absolutely on the moving finger. No fatigue.

Subject M.

First trial.—Starting cue was a visual image of the movement to be made, which was controlled by both visual and kinaesthetic perception. Attention was focused on the ring finger, but oscillated to the other fingers. Conscious of strain in all the fingers.

Tenth trial.—Auditory cue. Movement of ring finger was controlled by visual perception of record. Conscious of good control of ring finger. Visual perception of the little finger showed that it was moving, but had no kinaesthetic perception of it. Attention on record and on the cause of the movement of the little finger.

Subject P.

First trial.—Auditory cue. Visual perception of movement. Peculiar strain in the metacarpo-phalangeal joint. Attention was focused on the ring finger but was attracted to the little finger when it moved.

Eleventh trial.—Auditory-kinaesthetic cue. Kinaesthetic perception of movement was localized in the metacarpo-phalangeal joint of ring finger. Other fingers were completely relaxed. No kinaesthetic perception of them or sensation in them. Had a visual perception of them. Attention was focused on the movement of the ring finger.

Subject B.

First trial.—Auditory-kinaesthetic cue. Attention oscillated from ring finger to other fingers. Attention was really on the group. Was conscious of poor control. Visual perception of record and of moving finger were the control processes. The kinaesthetic perception was vague.

Eleventh trial.—Auditory-visual-kinaesthetic cue. Watched the record as it was being made on the drum very closely; fingers were controlled in this way. Had a visual perception of the fingers occasionally. Attention was focused on the ring finger most of the time, but the other fingers were in the field. Kinaesthetic perception of the group helped to control the process.

Subject S.

First trial.—Auditory cue. Conscious of poor control. Attention was on little and middle fingers chiefly in order to keep them from moving. It took little attention to keep ring finger moving. Attention to other fingers made control of them easier.

Eleventh trial.—Visual cue. Watched the record as it was being made on the drum; also had a vague kinaesthetic perception of the movement. Was conscious of good control. Attention was focused on record most of the time, but it oscillated. Conscious of irregular movement of ring finger due to strain and fatigue. Not conscious of middle or little finger.

2. *Summary of Right Hand Lateral Movement*

Movement in the lateral direction was learned much more rapidly than movement in the vertical plane. This result is probably due to the practice and training acquired in the previous movement. No unqualified assertion can be made, however, for transfer of training was not the problem immediately in hand and no adequate control tests were employed to justify sweeping affirmations regarding this point.

P.'s initial cue was uniformly kinaesthetic throughout the tests on lateral movement. Adjustments were always made in advance of the movement, and the signal seemed simply to set off the movement for most of the subjects; but P. always reported a kinaesthetic idea of the movement to be made as preceding the actual movement.

Sn.'s initial cue was usually auditory-kinaesthetic, but occasionally she reported a visual image of the movement to be made as her starting cue and once the visual perception of the moving drum. Her fingers were adjusted and she was waiting with strained attention for the signal and as the drum started to move before the signal was given, the visual perception of the rotating drum set the finger to moving almost automatically.

The initial cue of G. was rather evenly divided between visual-kinaesthetic and auditory-kinaesthetic, the auditory predominating. But M. on the other hand reported a visual cue only three or four times during the whole series. His cue was usually auditory. B.'s cue was usually auditory-kinaesthetic, but he frequently reported auditory-visual-kinaesthetic as his starting cue. P.'s initial cue was invariably auditory-kinaesthetic.

The *control* processes of the subjects were made more varied than in the preceding series. During one experiment one mental process would be the chief element of control, and during the next experiment another sort would predominate. At other times two or three mental factors would enter almost equally. Visual perception of the record and kinaesthetic perception of the moving finger were the most common controls.

G. reported visual perception of the record as it was being made on the drum by the recorder and kinaesthetic perception of the moving finger as the usual control processes. She emphasized the importance of the kinaesthetic factor which was localized in or near the metacarpo-phalangeal joint. She found, however, when she directed visual perceptual attention from the record to the fingers, that control was lessened and that it was necessary to watch the record intently in order to make the control perfect. It would seem that the visual perception of the record was a very important element of control, both of the moving finger and of the other members of the group.

Sn.'s movement was controlled by visual perception of the moving finger and by kinaesthetic perception of the movement also. She always watched intently the moving finger. This was her chief source of control; the kinaesthetic element was only supplementary to the visual. The extent of movement was controlled by the kinaesthetic perception which was usually reported as vague.

M. tried to control his movement in the lateral direction during the first set of experiments in this series by visual perception of the ring finger which was supplemented by kinaesthetic perception of the movement. But this method was not successful. In the next place he tried watching the record intently as it was being made on the drum. This method gave better control and was used until the process was practically automatic. The kinaesthetic element was recognized and used as an element of control throughout the entire series.

P. tried various means of control: at first he watched the moving finger but failed to gain control; in the second place he tried watching the record, which gave better results; in the third place,

he alternated between visual perception of the record and visual perception of the fingers. Kinaesthetic perception of the moving finger was recognized as an important element of control. Once he recognized it as the only element. The kinaesthetic sensation which gave rise to the kinaesthetic perception was always localized in the metacarpo-phalangeal joint of the ring finger.

B. tried various methods of control. Watched the fingers at first, but that method was not successful. Visual perception of the record assisted by kinaesthetic perception of the moving finger seemed to give the best results. He was not able to make a perfect record during the entire series.

Visual and kinaesthetic perception of the members of the group were the elements of control used by S. during the first part of the lateral movement. This method did not seem to give good results, but the visual perception was supplemented by kinaesthetic perception of the moving finger. His visual perception of the record became very vivid while the kinaesthetic perception was vague toward the close of this series.

The process of inhibiting movement in the fingers to be kept quiet depended upon muscular and tendinous sensations during the first stage of the control. Three of the subjects, however, used visual perception of the fingers and also visual perception of the record as elements of control. In the lateral series they relied entirely on muscular strain to control the quiescent members of the group during the first trials. All the subjects reported the tendinous and muscular strain in these fingers during the first several trials. One of the subjects emphasized visual perception of the fingers as the chief element of control; three, visual perception of the record.

c. General Summary of Series I

There are three rather definitely defined stages of the inhibitory process. The first is the stage of muscular and tendinous tension in which the subject tries to inhibit the little and middle fingers by keeping the muscles tense. In the second stage, the muscles are partially relaxed, and the muscular sensation is vague, and the record becomes approximately perfect. In the third stage, the muscles become completely relaxed, the subject

is not conscious of the non-moving members of the group or at most only vaguely conscious of them, and the record is usually perfect.

Quite frequently, however, the middle finger or the little finger moves, and yet the movement does not give rise to any kinaesthetic sensation and so the subject does not know that any movement has taken place until he examines the record. On the other hand, the subject frequently reports kinaesthetic perception of the movements of the other members of the group when the records show that no movement has taken place. These cases seem to be illusions of movement due to muscular tension which gives rise to vivid kinaesthetic images of the supposed movement. Complete relaxation of the inhibited members seems to be the goal of perfect control; and this is attained by withdrawing the attention from the non-moving members and by focusing it on the moving finger.

The field of attention usually includes all the members of the group. The movement begins with the focus of attention on the movement of the ring finger; but the muscular and tendinous strain in each finger seems to cause the attention to oscillate from one member of the group to another. The introspective reports of all the subjects show that voluntary attention always preceded the adjustment and movement of the ring finger; but they show also that the involuntary and non-voluntary movement of the other members of the group were followed by attention to them. Their movements did not ordinarily follow upon attention to them, but when the focus of attention went to them it was usually after their movement had begun. The process of attention was always most active at the point where new adjustments were needed to control the situation.

The conscious elements in the focus of attention varied in the first part of each series. Each of the subjects began the movement in the lateral direction by trying to fixate upon the visual perception of the moving finger; but the introspective reports show that the kinaesthetic perception of the moving finger was more vivid than the visual perception during the first part of the series. At this stage of the experiment the attention

oscillated. But as the control became more perfect, attention became focused on the kinaesthetic perception of the moving finger, the visual perception of the record, or the visual perception of the moving finger. G. used the first form of control, M. the second form, and Sn. the third form; P. used both the first and second forms with preference for the first; B. used the same forms as P. but with preference for the second form. S. focused his attention on the record with very vague kinaesthetic perception of the movement.

Series II. Distractions and Limitations—Seven Subjects

1. The Blindfold

The experiments of Series II followed immediately those described in Series I, with the same reagents.

a *Purpose*

The purpose of the blindfolded series was the elimination of the sensory element of visual control in order to enable the subject better to estimate the value of visual perception in the control processes, and especially its significance in comparison with the ideational visual element. One of our subjects immediately substituted the visual image of the movement for the visual perception and so his control was not affected. As a rule, however, the cutting off of the sensory visual element affects both movement and control processes until the subject can readjust himself to the new condition. This is true despite the fact that kinaesthetic, tactual, and auditory sensory material and visual ideational material are still available.

The cutting off of the visual perception affected the regularity and the extent of the movement of five of the subjects. The muscular sense was soon successfully used to gain control over the *extent* of the movement and its regularity. But the regularity of the *rate* of movement was controlled invariably by the auditory factor—the tick of the time marker, the tap of the thimble, or an imagined rhythm.

A metronome was introduced into the experiment primarily for the purpose of distraction, but from the first it was a positive help to most of the subjects; it made their records regular and

uniform in height. When the records had become thus regular and substantially free from error, the metronome was set at a faster rate—eighty strokes per minute, and then changed to sixty and back again to eighty during one trial. Two metronomes were used, each set at the regular rate, so that the change from the faster to the slower rate could be made without losing a beat. The change of rate distracted the attention of the subjects for a short time, but each rapidly gained control again and moved with the rhythm of the metronome. The change from the faster to the slower movement caused more difficulty than the change from the slower to the faster rate.

Counting was used as a distraction; the subjects were required to isolate the counting from the movement.

The subjects were also at times instructed to recite a familiar poem while moving the finger in time with the metronome but were required to isolate the rhythm of the poem from that of the movement and the metronome. As a further distraction, the beat of the metronome was changed during the test from 84 to 48 and back again from 48 to 84.

The subjects were further required to read easy prose, and at the same time move with the tick of the metronome, and to isolate the rhythm of articulation from that of the movement.

b. *Introspective Reports*

Subject G.

The movement was initiated by an auditory-kinaesthetic cue. Kinaesthetic perception of the ring finger was the principal control factor, but a vivid visual image was present during the whole trial. Other fingers were controlled by pressing them down on the table. Attention was focused on the perception of the moving finger—the visual image being emphasized as an element of consciousness but not regarded as a factor of the control process. Was conscious once, through tactile sensation, of the movement of the middle finger.

Subject Sn.

Auditory-kinaesthetic cue—auditory element being stronger than the kinaesthetic. Had a visual image of the whole group. Sensations in the ring finger, and sensation of touch when the finger came down on the table controlled the movement. Other

fingers were relaxed and hardly thought of. Attention was focused on the movement of the ring finger.

Subject M.

Auditory-kinaesthetic cue. Kinaesthetic perception of the ring finger was the control process. No visual images of any kind. Other fingers were relaxed but they moved slightly, though their movement did not give rise to kinaesthetic sensations. Attention was focused on the feeling of the movement. The blindfold seemed to have very little effect. Kinaesthetic sensations came from every part of the middle finger. Tactile sensations were localized in the tip of the little finger.

Subject P.

Kinaesthetic cue. General idea of movement controlled the process, with very vague consciousness of what was going on. Had no visual image at all. Did not think of the other members of the group. Attention was not focused on anything. Movement was automatic.

Subject B.

Auditory-kinaesthetic-visual cue. Kinaesthetic perception of the ring finger and visual image of it were the control processes. Other fingers were controlled by tactile sensations and by sensations of tendinous and muscular strain. The visual image of the movement was vague and exaggerated both in its amplitude and accuracy. Attention oscillated. Was conscious of perfect control. The visual image took the place of the visual perception. Kinaesthetic perception was the chief control process. Articular sensations were localized in the metacarpo-phalangeal joint.

Subject S.

Auditory-kinaesthetic cue, the latter being much stronger. Had hand adjusted waiting for the signal. Kinaesthetic perception of the ring finger and visual image of it were the control factors. Could not decide which was the stronger. Movement was more irregular than usual, but the other fingers did not move. Slight strain in the ring finger. Other fingers were held down by tendinous and muscular tension and by sensations of touch as they lay on the table.

c. *Summary of Results of Blindfold*

Visual perception as a control factor was of course completely eliminated by the use of the blindfold; those subjects that relied on visual control were stimulated to try and substitute the visual image for visual perception. One subject was able to make this substitution at once—using the visual image both as a starting

cue and the principal element of control. The blindfold caused great disturbance in the inhibitory control for the other subjects thus indicating the essential röle of visual perception in their motor coördinations. After a subject had gained sufficient control of the group to withdraw his attention from the members whose movements he wished to inhibit, any non-voluntary movement of the latter attracted attention to them again.

2. Blindfold, Metronome and Counting

a. *Introspective Reports*

Subject G.

Kinaesthetic image of the movement was the starting cue. Vivid kinaesthetic perception of the ring finger, but vivid visual images of both the ring finger and the metronome were present throughout the test. Other fingers were kept down on the table by pressure. Had a visual image of them. Attention was primarily on keeping with the rhythm of the metronome, and secondarily on the amplitude of the movement. Had articular sensation in the metacarpo-phalangeal joint, and tendinous sensation in the first phalanx of the ring finger.

Subject Sn.

Auditory-kinaesthetic cue. Had a kinaesthetic image of the upward movement before it began. Movement was controlled at first by visual image of the ring finger, and then the idea of the rhythm of the metronome and of keeping time with it were the principal factors of control. The visual image still continued, and also vague kinaesthetic perception. The other members of the group were relaxed and so little attention was paid to them. Attention was centered on the movement and on the metronome.

Blindfold and Counting Series

Subject G.

Kinaesthetic cue. Had a vivid visual image of ring finger throughout the whole trial, and also vague visual image of the group. Heard the rhythm of the movement all the time—the thimbles hitting the table. Had a tendency to make the counting twice as fast as the movement, and had to keep pausing to keep from doing this. Movement was controlled by kinaesthetic perception of the ring finger. It was easier to count regularly than to keep the movement regular. Other members of the group were not in consciousness. Attention was centered on the amplitude and regularity of movement. Muscular strain in forearm. Counted to III.

Subject Sn.

Auditory cue. Counted and moved together. Controlled the movement by counting and by kinaesthetic perception—articular sensation in the metacarpo-phalangeal joint of the ring finger. Attention was on the regularity of the movement—both the amplitude of the curve and the distance between the waves as shown on the record. Paid little attention to the other fingers—knew they were on the table by sense of touch. Sn. counted just as she moved—could not count otherwise. Could not separate movement and counting. Once when she lost breath in counting, she held the finger back until counting began. Counted to 121.

b. *Summary of Results of Blindfold, Metronome and Counting*

Neither the metronome sounds nor the counting affected the initial cue of the subjects. The method of control was essentially the same as before. The counting greatly distracted one subject, so that he was not able to inhibit the movement of the other members of the group. Another could not separate the counting and the movement; the two rhythms ran together. A third tended to do the same, but with great effort he was able to separate them. Four of the subjects counted faster than they moved. The counting caused oscillation of attention between the counting and the moving. Attention seemed always to go to the less automatic process—to the point where new adjustments were needed.

3. Series Blindfolded, Reciting Poetry, with Metronome

(*Rate changed from 84 to 48 and back again from 48 to 84*)

a. *Introspective Reports*

Subject G.

Cannot remember starting at all. No visual image of movement. Vague kinaesthetic perception of moving finger. Attention oscillated from trying to repeat the poem and trying to listen to metronome. Embarrassed by not keeping the rhythms together. Tended to keep the rhythm of metronome and poem together rather than finger and metronome.

Subject Sn.

Auditory cue. Attention was focused on repeating poem. Controlled moving finger by rhythm of metronome. Great tendency to recite rapidly when the metronome was moving fast and slowly when the metronome was moving slowly. Difficulty in

keeping from reciting rhythmically. Conscious of good control. Little attention to fingers. Much amused.

Subject M.

Auditory cue. Kinaesthetic control of ring finger. Attention on rhythm of metronome. Conscious of movement of little finger.

Subject P.

Auditory cue, but it was not distinct. Kinaesthetic control of ring finger. Attention was focused on reciting the poem. Not conscious of other fingers.

Subject B.

Auditory cue. Attention oscillated between the reciting of the poem and the tick of the metronome, and the ring finger. Conscious of imperfect control. Vague kinaesthetic perception of moving finger. No visual image.

Subject S.

Auditory cue. Attention on keeping rhythm of movement with rhythm of metronome. Conscious of the movement of little finger by sensation of touch and by kinaesthetic perception.

b. *Summary of Introspective Reports*

In the tests preceding these in which a familiar poem was repeated during the movement, the subjects were directed to move with the rhythm of the metronome. In the poem test, the subjects still kept time with the metronome, but tried to isolate the vocal control from the control of the finger. This necessarily caused oscillation of attention, and in listening to the metronome the subject would drift into the rhythm of the metronome in reciting the poem. This oscillation caused some embarrassment at first and imperfect control, but after a few trials the control became perfect and automatic. The reports show that the subjects depended chiefly upon auditory control processes.

4. Reading Prose

a. *Introspective Reports*

Subject G.

Kinaesthetic cue, but started before the signal was given. Became interested in the reading and paid little attention to the movement, which was controlled by kinaesthetic perception. Had an occasional visual image of the ring finger. Wondered if she should not be asked how much she remembered of what she read.

Wondered if she was reading intelligibly, and if record was regular. Reading did not affect movement.

Subject P.

Attention was concentrated on the reading and it was difficult to determine what the starting cue was—but started with the signal bell. Attention oscillated between the fingers and the reading, but for the most part it was on the latter—both the words and thought. Got the thought. Movement of the ring finger, which was almost automatic, was controlled by vague kinaesthetic perception of it. Articular sensation in the meta-carpo-phalangeal joint. Other fingers were rigid at first, and then they were hardly in consciousness.

b. *Summary of Results of Reading Prose*

The reading of easy prose sometimes caused the attention to oscillate between the reading and the movement of the finger or between the reading and the sound of the metronome. There was a tendency to read faster when the metronome changed from slow to fast and *vice versa.* There was not so much tendency to read rhythmically as there was when the poem was recited, but it required more practice to acquire automatism than in the previous series, and there was a greater oscillation of attention of four of the subjects; while the attention of the other two (ladies) oscillated, it was more strongly concentrated on the reading. The visual-articulatory distraction of reading the easy prose caused more disturbance of the control than the recall-articulatory distraction of reciting the familiar poem.

Series III. Pressure Curve

a. *Object of Pressure Test*

The reports from several of the subjects in the tests described above raised the question as to the importance of pressure as an element of the process of inhibition, as they frequently reported that the middle and little fingers were controlled by means of pressure on the tips of the fingers. In order to obtain an objective record of the pressure of these fingers, to compare the relative value of the methods of relaxation and contraction, to show the relative amount of pressure used in inhibition during the learning process, the effect of rate on pressure, and the rela-

tion of rate to fatigue, three new groups of six subjects each were selected. All were right handed.

1. GROUP I

O., Sc., and G. had had no preliminary training in finger movements. M. had taken a few piano lessons when a little girl but had practiced none since. Motor control was naturally easy for her. S. used a typewriter occasionally but had never taken lessons. V. had never taken piano lessons but amused himself occasionally by playing.

Three of the subjects, V., Sc., and S., were instructed to relax their fingers, and the other three, O., G., and M., to keep their fingers rigid, the antagonistic muscles being kept tense. The subjects were instructed to move the tip of the ring finger, using the metacarpo-phalangeal joint as a pivot, through the space of two centimeters at the rate of two times per second for one hundred seconds. After resting for three minutes, a second test was given. The amplitude was somewhat irregular because the subjects were not able to judge accurately the distance.

b. *Variation of Pressure*

During the first stages of the learning process the amount of pressure varied greatly during each test; the pressure curve showed sudden, sharp, and irregular changes. But after the subjects learned to inhibit the movements of the little and middle fingers, the pressure curve remained practically constant and the amount of pressure was very slight. Two of the subjects resorted to the expedient of pressing down the palm of the hand or the thumb in order to keep from pressing down on the pegs which supported the middle and little fingers. The pressure curve of the subjects that were instructed to relax was more regular and less in extent than the curve of those who were directed to keep their fingers rigid.

c. *Summary of Individual Reports*

The mental antecedents, or cues, that initiated the movement of the ring finger in each case were essentially the same as those reported in the previous series. The auditory cue, however, was reported more frequently than any other during this series. One

reagent always innervated his finger so far as to be ready for the signal which seemed to touch off the movement. Another always had a visual image of the movement that he was about to make.

The mental processes that accompanied the movement of the ring finger varied. One reagent repeated mentally "up, down", which seemed to be his chief element of control. He was conscious of tactile sensations in the tip of the finger and sometimes reported sensations of strain in the metacarpal region near the metacarpo-phalangeal joint, but as a rule the kinaesthetic sensations did not rise above the threshold. Other reagents reported tactile, articular, and kinaesthetic sensations as elements of control. The non-moving fingers, during the learning process, were controlled by slight contraction of the antagonistic muscles.

Fatigue usually began to appear at the end of eighty to one hundred seconds when the subjects were required to move at the rate of one hundred and twenty times per minute; and when they were required to move for a longer period at that rate the subjects could not as a rule inhibit the movement of the other fingers. When only three or four minutes intervened between two tests, the inhibition of the little and middle fingers was not so good during the second trial as in the first on any given day. Articular sensations were usually localized in or near the metacarpo-phalangeal joint and as fatigue increased, tendinous and muscular sensations were felt in the metacarpal and carpal regions and in some instance sensations of strain were experienced in the fore-arm.

Automatism was acquired more rapidly by the subjects that were instructed than by those that were not instructed in the series described above. Twenty-five to thirty trials were required to gain complete automatism. The reagents that were instructed to hold their fingers rigid required about twenty per cent more trials than those that were instructed to relax.

2. Group II

a. *Right Hand Relaxed*

The six subjects of this group began the tests with the fingers of the right hand and were instructed to relax and move at the

rate of 132 per second. As fast as control was gained, the rate was increased to a point where the subject could not inhibit the movement of the other fingers and practice was continued at the faster rate until control was gained. This process was continued until the subject gained control at the fastest rate possible, and then a rate faster than the subject could move and control the other fingers was required.

b. *Left Hand Contracted*

When control was practically perfect with the right hand relaxed, the subjects of Group II were given tests with the fingers of the left hand contracted. The rate was increased as stated above. Comparison of these tests with Group III, using right hand, fingers relaxed, is given below.

Group II gained control with fingers relaxed considerably faster than Group III, fingers contracted. This might seem to be due to the fact that Group II used the right hand while Group III used the fingers of the left hand; but when the instructions were reversed, the relaxed fingers gained control more quickly than those that were contracted. *On the whole, our experiments seem to show that control is gained more quickly when the fingers are relaxed during the learning process.*

As shown in Group I, the pressure curve becomes smaller with practice, and is very small after the subject has gained control and moves at a moderate rate; and when perfect inhibition is attained, the pressure curve becomes a straight line, showing a slight degree of pressure; but when the reagent is required to move fast enough to require effort, the pressure curve tends to increase in extent and to mark time with the moving finger. *When the inhibition is incomplete, pressure is always shown to be present in all normal tests.* Three of our subjects, that were acquainted with the object of our tests, avoided pressure on the tips of the fingers by pressing down on the palm of the hand.

c. *Effect of Rate on Pressure and Fatigue*

The effect of rate on pressure was marked. When the subject first begins to learn the movement, pressure is shown at each movement by the inhibited fingers, but the irregularity of the

pressure curve gradually disappears by practice at the slower rate. By increasing the rate, the pressure curve rapidly increases, and tends to conform to the symmetry of the curve made by the moving finger. As the maximum rate is approached, the pressure curve suddenly increases in amplitude and conforms in time to that shown by the moving finger. When the rate is faster than that at which the subject can move the ring finger and inhibit the movement of the other fingers, the pressure curve becomes irregular both in amplitude and rate.

Speaking broadly, we find that as the rate increases in an arithmetical ratio, fatigue increases in a geometrical ratio. When the subject was required to move at the fastest rate possible, extreme fatigue occurred at the end of fifty or sixty seconds, and the amplitude of the curve was greatly reduced and frequently the subject was compelled to stop moving the finger because of exhaustion. After a given rate becomes well automatized, movement may continue for a considerable time without fatigue. A rate that is easy for one subject may be utterly impossible for a subject of a different type. When the subjects were required to 'contract,' fatigue was experienced more quickly than in the tests in which they were instructed to relax. In some instances the fatigue became so painful at the end of eighty or ninety seconds that the subject was compelled to stop. As a rule, the amplitude of the curve shown by the moving finger was less during contraction than during relaxation, and the pressure curve was greater.

3. Group III

a. *Left Hand Contracted*

Group III of the Pressure Curve Series began with the fingers of the left hand contracted and with a rate of sixty per minute; the rate was gradually increased as soon as the subjects gained approximate control, until a point was reached at which the subjects could go no faster and keep control of the non-moving fingers.

b. *Right Hand Relaxed*

Group III required approximately twenty per cent more time

to gain automatism by the method of contraction with the left hand than Group II by the method of relaxation with the right hand. But when Group II used the fingers of the left hand contracted, and Group III, the fingers of the right hand relaxed, the former required twenty per cent more tests than the latter.

c. *Methods Compared*

All our tests accordingly seem to show that relaxation is the better method. In both cases, when change was made from right hand to left and from left to right and the method reversed, it required approximately but half as much time to gain control after the process had been learned by the fingers of the other hand. The effects of cross education were thus apparent even though the method was reversed.

TABLE SHOWING NUMBER OF TESTS REQUIRED TO GAIN CONTROL

GROUP II

	Right Hand Relaxed		*Left Hand Contracted*	
Subject	Rate	Tests	Rate	Tests
Cr.	132—208	31	60—200	20
B.	132—208	18	144—208	22
D.	132—208	12	144—208	10
F.	132—208	22	60—208	12
M.	120—192	28	60—184	19
R.	120—192	27	60—192	16

TABLE SHOWING NUMBER OF TESTS REQUIRED TO GAIN CONTROL

GROUP III

	Left Hand Contracted		*Right Hand Relaxed*	
Subject	Rate	Tests	Rate	Tests
Br.	60—208	35	60—192	16
Bu.	60—200	30	60—200	15
C.	60—200	38	60—200	19
Cu.	60—208	32	60—208	14
G.	60—184	26	60—192	14
W.	60—208	29	60—208	17

SERIES IV, FINGERS UNSUPPORTED

1. *Preliminary Statement*

The introspective reports from certain subjects in Series I, II, and III showed that tactile and pressure sensations due to the contact of the fingers with the table were factors of the control processes in each series. Another set of experiments in which the hand was unsupported except just above the carpal joint, was planned in order to test further the nature and value of the

tactile and pressure elements as factors of the control processes. For this purpose a group of seven new subjects was selected. Both right hand and left hand series were given. During the right hand tests, the reagents were instructed to relax the muscles controlling the fingers; in the left hand tests, they were instructed to contract. The introspective reports of the subjects in the right hand finger movements are given below:

2. *Introspective Reports*

Eyes Open

Subject J.

At the first, the experiment of moving the ring finger independently of the other fingers seemed impossible. The visual image came to the front first, showing how the finger would look when pushed down. Then the kinaesthetic sensations [or images] located in the muscle on the under side of the finger, seemed to pull the finger down. The other fingers moved down, too, to some extent, out of sympathy. Soon a keen sensation of fatigue on the inside of the palm and forearm made it nearly impossible to move the finger.

After a number of experiments the fatigue and kinaesthetic sensations almost disappeared. Part of the time the rhythm of the tactile sensations in the tip of the finger helped the control. Then the kinaesthetic and visual elements returned, and finally the movement became automatic.

Subject M.

Finger was innervated ready for the signal and so moved at the sound of the bell. Kinaesthetic sensations were felt in the volar side of first phalanx and in the metacarpo-phalangeal joint. Had a vague visual percept of the movement. Tactile sensations in the tip of the ring finger were elements of control. Was not conscious of middle finger, but conscious of tactile sensations in tip of little finger where it touched the thimble.

Subject P.

A visual image of the required movement immediately followed the signal. Visual perception controlled the moving finger at first, and then kinaesthetic sensations seemed to be the principal elements of control. The muscles of the other fingers were felt to be contracted, but they did not move. Watched the movement at first with reference to some spot on the table in order to regulate the distance. When the finger was not looked at, tactile and kinaesthetic perception guided the movement.

Subject S.

A visual-kinaesthetic image preceded the movement which was controlled by visual and kinaesthetic perception. Other fingers were out of consciousness most of the time. Arm became fatigued before the close of the test. The kinaesthetic sensations were localized in the volar side of finger from the tip of the metacarpo-phalangeal joint.

Subject A.

Kinaesthetic image always preceded the movement which was controlled by kinaesthetic perception. The other fingers dropped more and more out of consciousness. There seemed to be a peculiar connection between the kinaesthetic sensations and the rhythms of the time-marker and the motor.

Subject F.

Finger was innervated ready to move, and the signal simply touched it off. There seemed to be a tactile image of the ring immediately preceding the movement, but it could hardly be distinguished from the real sensation. Tactile sensations in the tip of the finger and kinaesthetic sensations in its volar side were the elements of control. Sensations of fatigue were felt in the hand and forearm. Other fingers were not in consciousness.

Subject G.

The initial cue was a visual-kinaesthetic image. Visual and kinaesthetic perception of the moving finger. The kinaesthetic sensations were felt in the metacarpo-phalangeal joint, and sensations of fatigue in the hand, wrist, and forearm. Other fingers dropped out of consciousness after control was attained. The kinaesthetic sensations seemed to be the principal elements of the control process.

3. *Summary of Introspective Reports*

The initial cue and the control of the moving finger do not differ essentially from those in the former series. More practice was required to learn to inhibit the movements of the other fingers than in the series in which the fingers were supported on the table. The pressure sensations were eliminated, but the tactile sensations produced by the thimbles continued to be elements of control, though not so valuable as those produced by contact with the table. The kinaesthetic sensations did not differ essentially from those described in the former series: they were localized chiefly in the volar side of the phalanges, and in the metacarpo-phalangeal joint.

The value of support and of the contact of the fingers with the table is shown by the fact that in the unsupported series, the number of tests required to gain control and inhibit needless movement was more than twice that necessary in the tests in which the hand lay flat on the table. It was difficult for the subject to hold the non-moving fingers in a given position, even when watching them.

The rate of two times per second was required of each subject, and caused fatigue when continued for over a hundred seconds. Sensations of fatigue were felt not only in the finger and in the metacarpo-phalangeal joint but frequently in the metacarpal and carpal regions, and even in the forearm. When the rate was made faster than two per second, control became more difficult. When the metronome was set at 180, the reagent in order to retain control dropped his movement back to 90, accenting each alternate tick. All the subjects acquired control up to 130, but above that rate control seemed impossible for them.

The average time required by the seven subjects to secure automatism was fifty tests, or twenty-five days, two tests being given each day. Two of the reagents acquired control in thirty tests, while two others required fifty, and one required seventy. The time required to gain automatism in the unsupported series is thus found to be approximately twice that of the series in which the hand is supported on the table, the subjects being instructed to relax in each case.

Fatigue naturally occurred more quickly when the subjects were required to move rapidly, and while they were learning the movement. The sensations of fatigue were felt first in the volar side of the finger in the first phalanx, the metacarpo-phalangeal joint, the metacarpals, the wrist, and the forearm, in the order named—extending from the finger toward the arm and shoulder as the fatigue increased.

The reagents were instructed to move the finger a distance of two centimeters as in the former tests. It was thought best not to move a longer distance in the unsupported tests than the supported ones; for in the latter it is not easy for the average subject to move a greater distance without straining the finger; and

furthermore, the objective records are not easily preserved when the distance moved is more than two centimeters.

In the left hand tests the reagents were instructed to contract; control was gained in twenty tests, or two-fifths the time required for the right hand. In the uninstructed series, the left hand required only one-tenth as many tests to gain automatism as the right hand. This result was due presumably to the effect of central education. If this inference is correct, the method of relaxation is again shown to be better than that of contraction.

GENERAL SUMMARY OF PART I

1. All the flexor or extensor muscles controlling the movements of the members of a group tend to contract or relax simultaneously. On the physiological side there is a diffusion of the nervous impulse to the muscles whose contractions move the several members of the group; the motor discharge affects the muscular tonus of the whole organism. On the psychical side, there tends to be a diffusion of the attention to the several members of the group.

2. The problem of isolation of control in a group involves the task of draining the motor discharge into the nerve or nerves controlling the muscles concerned in moving the given member. The psychical phase of the problem involves the development, direction, and control of attention.

3. The inhibition of the movement of the other members of the group requires attention in the early stages of the process; the field of attention is the group and the focal point is usually the moving member during the learning process. When the subject learns to concentrate his attention wholly on the moving finger, the muscles controlling the other fingers become relaxed.

4. Inhibition of the movement of a part of the members of a group is due either to the contraction of the muscles controlling the inhibited members or to relaxation following upon non-attention to them.

5. Learning to relax is a necessary prerequisite both to voluntary movement and to non-voluntary inhibition. General relaxation is learned by learning to diffuse the attention—"by thinking

of nothing," as Professor James says. Local relaxation may be produced by fixed attention to some other part of the organism.

6. The development of voluntary control and the inhibiting and directing of the motor discharge are two phases of one total process.

7. During the learning process, the inhibited members exert a certain amount of pressure which gradually approaches zero as the movement becomes automatic.

PART II

Interpretation of Results and General Conclusion

At the risk of undue repetition of points already touched upon, we have brought together in the following paragraphs a few of the conclusions regarding the "cues," the "controls" and the essential aspects of attention and inhibition which we desire to emphasize.

1. *Initial Cue*

By initial cue we mean the immediate mental antecedent—sensation, perception, or image—of a movement. In so simple a case as that of the movement of a finger, it is not always easy to determine the mental processes that immediately precede the movement, for voluntary activity readily passes over in to mere automatism. But *during* the *learning* process, our tests show that the mental precursor of a *voluntary* act is characteristically sensation, perception, or image of some sort.

We tabulate below the results from six subjects of one hundred consecutive experiments on different days. The terms used in the table have their ordinary meaning as explained in Part I. In case one or the other element appeared more vivid, we have placed it first in the table.

Four of the subjects occasionally reported a general idea of movement as their initial cue, and five of them one or more times that the movement began automatically. The results given in the last two columns of the table seem to give some evidence in favor of the contention of Professor Woodworth and others that a naked thought can perfectly well perform the function of starting the motor machinery in action and determining the point and

object of its application. But this occurs only after automatism has been acquired, and not during the learning process. It is probably fair to mention the fact that the writer when acting as subject, never reported his initial cue as a general idea or as automatic. This may be due to his prejudice to the theory, which prevented his perceiving the "naked thought," since all the other subjects that continued the work to the end seem to report its presence occasionally, but only after automatism had been gained.

The one hundred tests given in the table were taken after the subjects had been practicing daily for nearly three months. The accuracy of the introspections can hardly be questioned. The table of results tells its own story. It shows that almost any sort of a sensorial image or idea—and possibly any sort of an idea—may start the motor machinery after the process has become practically automatic.

THE INITIAL TABLE SHOWING CUE OF ONE HUNDRED TESTS OF MOVEMENTS OF THE RIGHT FINGER

	One Test Being Given Each Day							
Subject	K	V	A	V-K	A-K	A-V	G-I	Automatic
G.	65	8	18	2	2	2	0	3
Sn.	4	33	76	1	9	1	6	3
M.	17	29	40	2	2	0	6	4
P.	40	5	36	7	6	3	1	2
B.	5	10	20	41	18	6	0	0
S.	24	18	43	1	8	4	1	1

K Kinaesthetic
V Visual
A Auditory
V-K Visual-kinaesthetic
A-K Auditory-kinaesthetic
A-V Auditory-visual
G-I General Idea

2. *Control Process*

By the control process we mean the mental factors active in guiding the moving finger in rate, regularity, and amplitude of movement. During the learning process kinaesthetic, articular, tactual, auditory, or visual elements were present. One of these factors was usually more vivid than the others. One subject seemed to depend upon kinaesthetic perception to guide the moving finger but immediately interpreted the situation in visual terms, whether the eyes were open or closed. Another relied almost wholly on visual perception or visual image to guide the moving finger.

Visual control does not always mean a visual perception or a visual image of the moving finger. The subjects frequently controlled the movement of the finger by watching the recorder marking the curve on the kymograph. While moving the finger in the horizontal plane, one subject controlled the movement by watching the upright rods to which the thimbles were attached. When the subjects were blindfolded, they substituted the visual image for the visual perception.

The kinaesthetic factors were essentially the same whether the eyes were open or closed, except that the blindfold usually served to bring them into relief and thus make them more vivid. The kinaesthetic sensations were usually localized in the metacarpophalangeal joint and the first phalanx and metacarpal of the ring finger.

Sensations of strain were quite frequently localized in the wrist, the forearm, and in the region of the scapula. Only one subject reported vivid sensations in the region of the scapula.

Tactile perception was an important element of control even more than our introspections would seem to indicate. It enabled the subjects definitely to locate the position of the finger at the beginning and end of each movement.

The auditory element also played an important part, especially with movements in the vertical plane. The metal thimbles in coming in contact with the table at the end of each movement made a slight rhythmic noise. The subjects would frequently regulate their movements by the tick of the time marker. As we have said before, when a metronome was used, the subject moved his finger more easily.

The mental processes accompanying the movements depend upon the habits and mental types of the subjects. By voluntarily emphasizing one mental process it may be made the principal factor of the control process. But if the subject is left to choose his own method he will use that most familiar to him.

When the movements became well automatized, the subject could let his mind run to the ends of the earth without affecting the results. Reading, singing, or reciting seemed to give one subject better control of the finger movement.

3. *Attention*

In order to succeed, it was necessary for the subject to concentrate his attention on the idea of the movement to be made, making it as definite and clear as possible. During the first stages of the experiment it was found necessary to keep the non-moving members in the margin of the field of attention with the idea in mind that they must not be moved.

The kind of imagery to which the attention was directed depended as already indicated upon the mental type of the subject. The auditory, kinaesthetic, and visual in the order named were the more common.

The process of learning to attend to the moving member was found to be the key to our problem. The more exclusively the subjects could direct their attention to the movement to be made, at the same time dropping out of consciousness as far as possible the fingers not to be moved, the more likely was the desired movement and inhibition of movement to be perfect. While learning to attend to the moving finger, the subject learned to single out the various kinaesthetic sensations aroused by the movement. He learned to distinguish and localize the tendinous, muscular, and articular sensations. These elements once brought into the focal point of consciousness became clear and definite.

When the tests were continued for a longer period than eighty to one hundred seconds, the subject was unable to concentrate his attention on the movement and the consequence was loss of control. When the subject was fatigued either mentally or physically by overwork before the experiment began, poor results usually followed—due as a rule to oscillation of attention.

4. *Inhibition*

We observed three rather definitely marked stages of the inhibitory process in our problem:

1. The stage of contraction of the antagonistic muscles.
2. The stage of partial relaxation of the muscles.
3. The stage of complete muscular relaxation.

We use the term inhibition of movement as synonymous with prohibition or prevention of movement, being aware of the fact

that the physiologist calls the first two stages innervation of the antagonistic muscles, and the third stage isolation of innervation.

During the first stage, the inhibition of the movement of the little and middle fingers was due to muscular and tendinous tension. When these two fingers happened to move, kinaesthetic sensations were usually localized in the first phalanges and in the metacarpo-phalangeal joints. The non-moving members were in the field of attention, but not in the focus unless the fingers moved. Attention being focused on the movement of the ring finger, consciousness of the other members became vaguer and vaguer from test to test. Finally the inhibited members became relaxed, and practically dropped out of consciousness. The consciousness of the non-moving members during the first stage consisted of visual images of the fingers or visual images of the record, kinaesthetic perception of them (in case they moved) and muscular, tendinous, and articular sensations.

The second stage is intermediate between the first and third. The muscles are partially relaxed and the muscular and tendinous sensations are vague and the process of inhibition is approximately perfect.

During the third stage, the fingers are relaxed and practically drop out of consciousness and during many of the tests dropped entirely out.

Tactile perception from the little and middle fingers reporting their position on the table and in the thimbles was an element of the inhibitory process. Frequently the subjects reported that the only consciousness that they had of the moving members was due to tactile sensations of the table.

Conclusion

It remains to summarize briefly the results of the various tests cited in the different parts of his paper. Part I attempted in the first place to throw into relief the mental processes utilized in initiating and controlling a special type of voluntary movement when no suggestions are given as to the method to be employed; and in the second place to determine, under like conditions, the mental factors involved in the process of inhibition. While the

reagents were left free to move without any embarrassment, the mental type of each determined the mental factors utilized in initiating and controlling the movement. With practice, however, both the initial cue and the several factors of control could be varied at will by the reagent by voluntary direction of the attention; *e.g.*, to the visual, kinaesthetic, tactile, or auditory factors. But definite ideational or sensorial processes—or both—were present so long as the movement was voluntary; after it became automatic, the movement could be initiated by means of a very vague idea and the control process was chiefly below the threshold of consciousness. The degree of automatism differed considerably in the several individuals of the five groups of reagents.

In the distraction experiments of Section II, the problem was to test the effect of elimination of the visual factor, and also the effect of centering the attention on the tick of the metronome, on reading, or counting, during the movement. Those reagents that depended upon visual perception to control the movement learned quickly to substitute the visual image for the visual percept and were able to get on almost as well as they did with the eyes open. Sometimes the kinaesthetic percept was immediately followed by a visual image. When the reagent gave attention to the rhythm of the metronome, control was easy and good; but when attention was focussed on reading, control was poor. One reagent, however, had better control when required to read or count during the movement. In this particular case, finger movements were so thoroughly automatized that close attention to the fingers seemed to lessen the control.

The initial cue was always an auditory, visual, tactile, or kinaesthetic sensation or image, or some combination of these, during the learning process. Only after the movement had become automatized did certain of our subjects report a general idea of the movement as the initiatory cue.

During the learning process, the control factors of the moving finger were visual, tactile, kinaesthetic, articular, and auditory, one or more of these being more important than the others, according to the mental type of the subject. But as the movement

approaches automatism, the subject relies on the kinaesthetic sensations localized in the metacarpo-phalangeal joint or in the first phalanx, to guide the moving finger. While the control factors may be varied to some extent by the will of the reagent, both observation and introspective reports show that the kinaesthetic element is the most important. Three of the subjects reported that they could control the moving finger better when they did not pay close attention to it, and especially when they did not watch its movements.

The effect of rate on control of the non-moving fingers showed great individual differences. For example, one of the reagents found difficulty in inhibiting the other fingers when the rate was slower than twice a second while another found it difficult to move at a rate faster than 84 per minute. As a rule, those reagents that take active part in athletics or command muscular dexterities like piano playing, can maintain control at a faster rate than others.

Fatigue was increased rapidly with the increase of rate. When the rate was made extremely fast for a given reagent, fatigue became painful before the expiration of a minute. But as we have stated in another place, twice a second was very fast for one subject while three times a second seemed easy for another.

The value of support and tactile sensations were shown in the "unsupported" series. The results of that series seem to show that when these elements are present the time of learning control is decreased about one half. The tactile element was important in gauging the extent of the movement and in keeping the non-moving members in position. While pressure seemed to be a means of resisting the overflow of motor discharge into the nerves controlling the muscles of the inhibited members, increased rate on the other hand increased the overflow and thus tended to prevent control.

In the distraction experiments of Series II, Part I, the reagent lost control for a time until he learned how to maintain the double process. As a rule attention went to the less automatized process. When the distraction was very effective, as in the case of reading an interesting story, the movement went on without

conscious control. However, there were two exceptions to this rule: two of the reagents found it necessary to focus attention on some factor of the motor process, either the kinaesthetic sensations localized in the metacarpo-phalangeal joint, or the tactile sensations localized in the tips of the fingers—the latter being the more important factor in the inhibition process. Certain of the subjects relied on visual perception to inhibit the movement of the fingers, while certain others reported that visual perception positively hindered both movement and inhibition; the second group were composed, however, of persons whose finger movements were well automatized.

Series IV emphasized the value of tactile sensations in both control of movement and inhibition. The time required to gain complete control of movement and inhibition was approximately twice that of the other series. The elimination of the tactile and pressure elements from the inhibitory process, compelled the subjects to learn to rely on other factors; this took time. Relaxation and contraction were the methods used.

The pressure curve was rapidly reduced in amplitude by practice; but a sudden increase of rate greatly increased the amplitude of the curve. A sudden motor discharge thus seems to overflow into all the members of the group and causes or tends to cause them to move. This overflow is controlled by practice up to a certain rate, beyond which control becomes impossible; the speed cannot be maintained, the movement becomes irregular, the amplitude decreases, and inhibition becomes impossible. The limit of speed varied in the different subjects. Two were able to make almost perfect records at a rate of 208 per minute while others were not able to go beyond 192.

Relaxation of certain of the muscle groups is an essential part of the acquirement of control. The methods of attaining relaxation have already been discussed.

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